Energy flow in the forward region at $\sqrt{s}$=0.9 and 7 TeV

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Outline

- Physics motivation
- Analysis strategy
- Corrections and systematic uncertainties
- Results

CMS reference: CMS-FWD-10-011

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Motivation

High energy collisions - large parton densities important:

- **High probability for multiparton interactions.**
- **Low x physics.**
- **Possible saturation effects.**

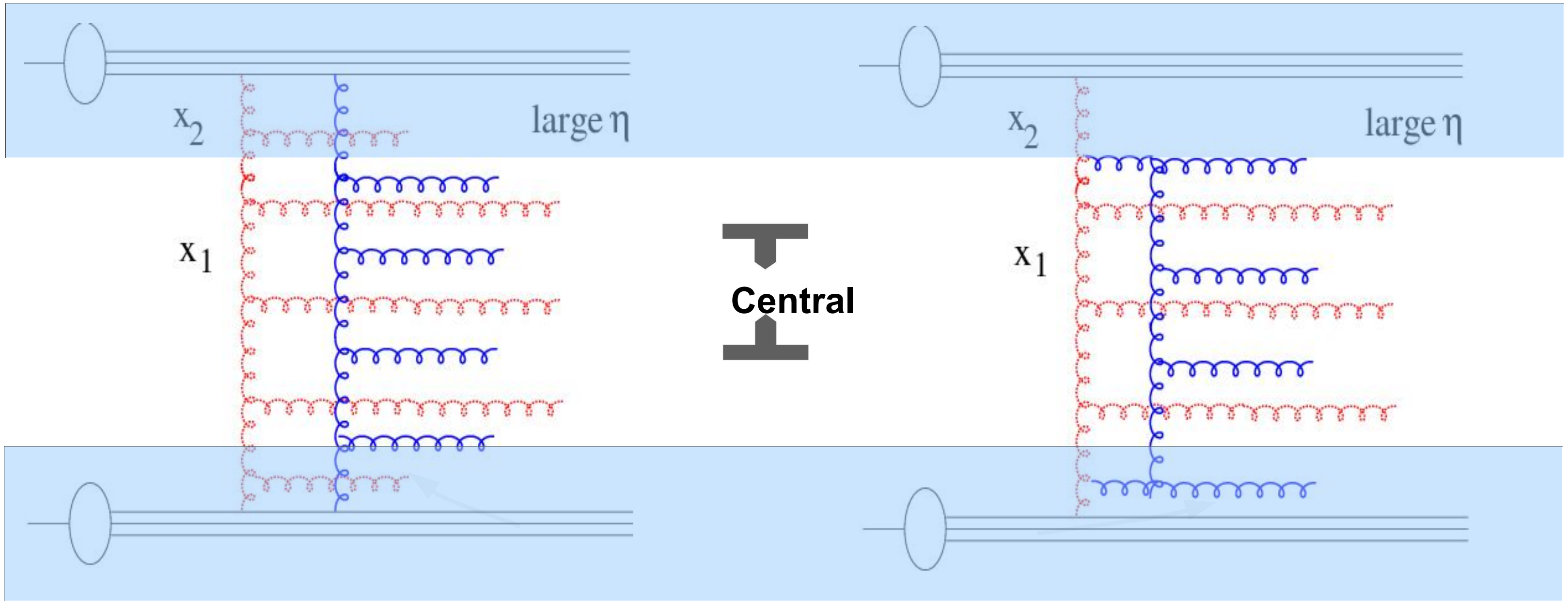
→ High sensitivity to QCD.

Forward region:

- **Long range in rapidity between forward and central activity. Opens up for higher order reactions.**

→ Further sensitivity to QCD.

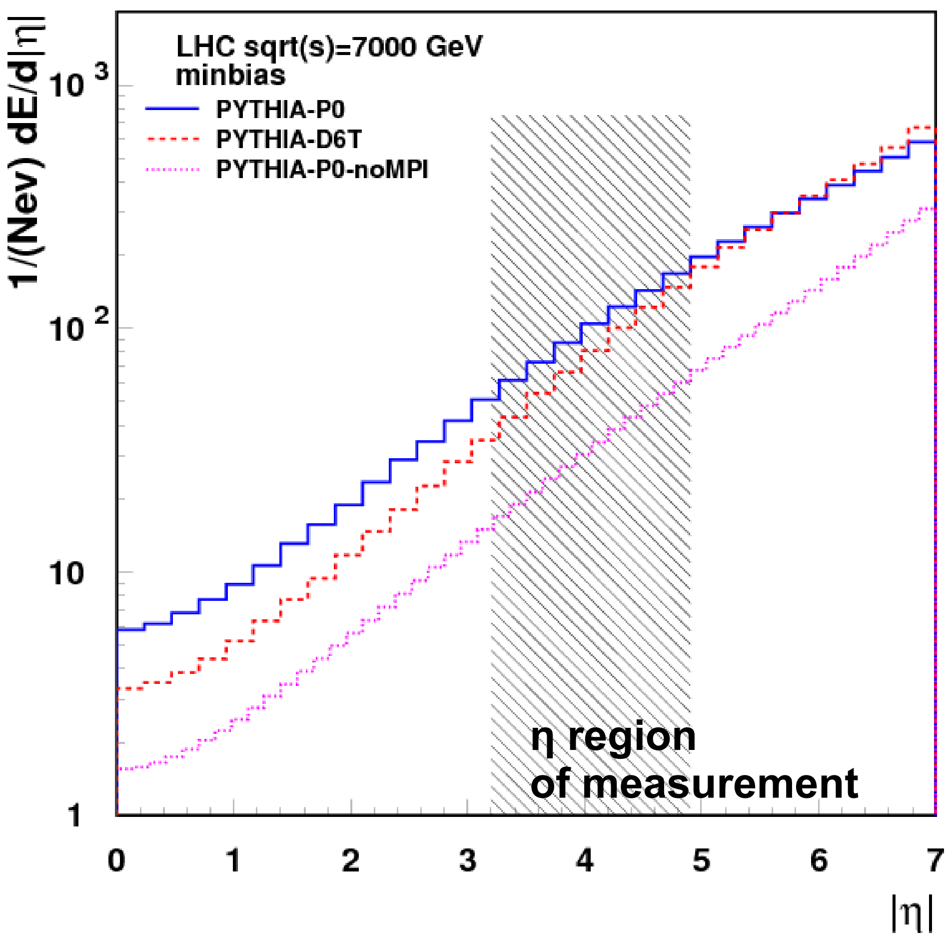
- **Energy flow in the forward region:**
  Information about color (re)connections to the proton remnant.

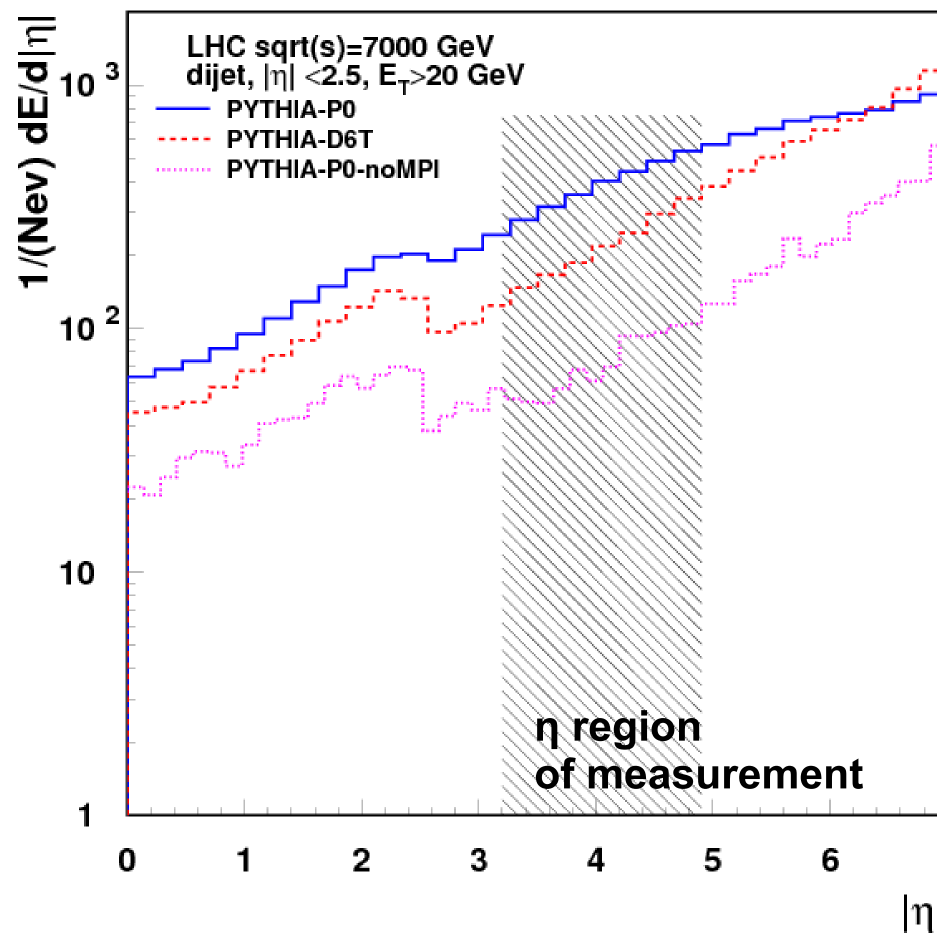


Forward energy flow

Motivation

MC studies of Energy flow for Minimum Bias and Dijet events.

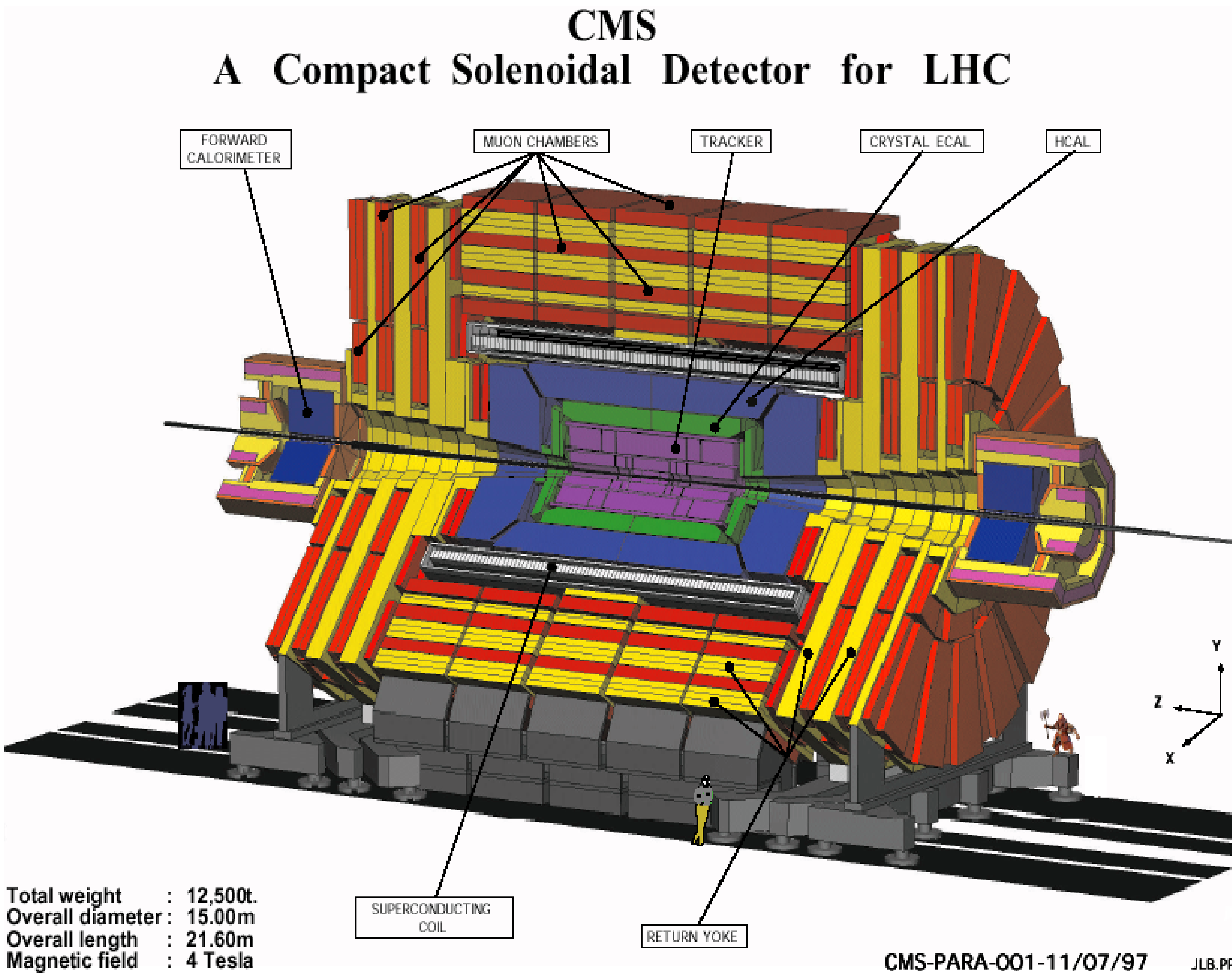




- **Tunes made to UE measurements in the central region.**
- **Use the forward region to explore the underlying event.**
- **Discriminate between models.**
- **Possibility to use data to improve MC models and tunes.**

The CMS Detector

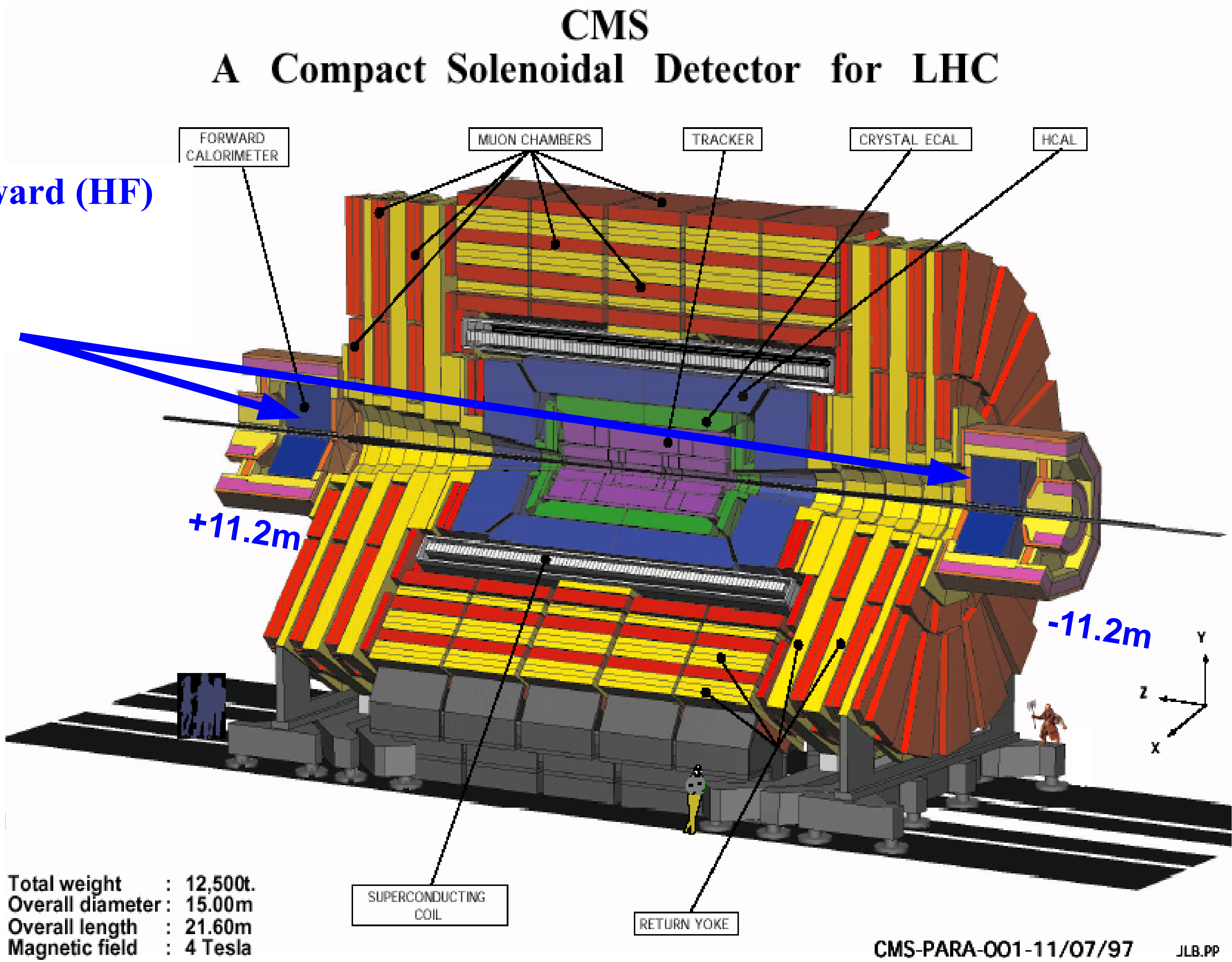
The CMS Detector



The CMS Detector

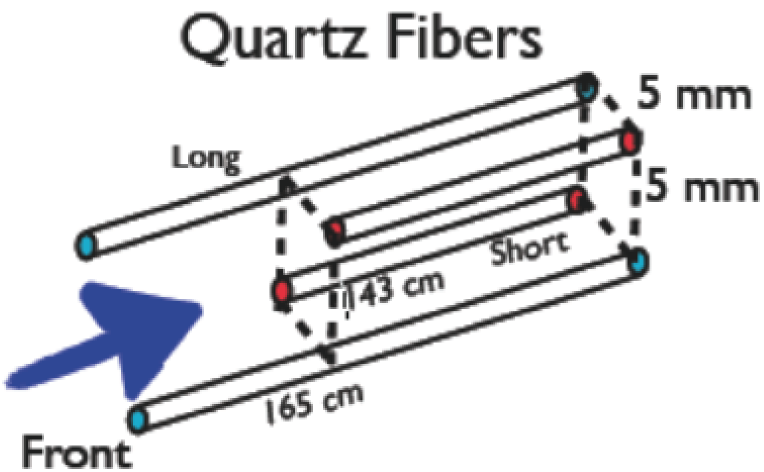
Hadronic Forward (HF) Calorimeters

$2.9 < \eta < 5.2$

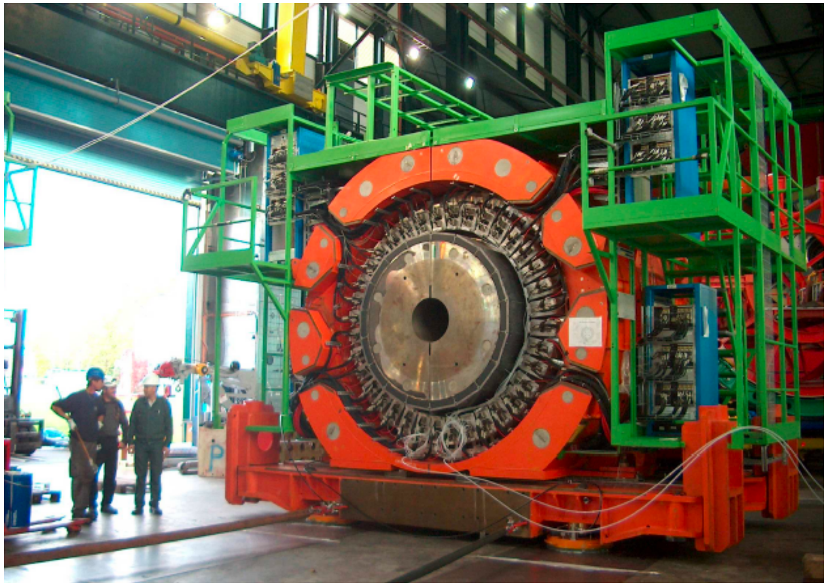


- Cherenkov light calorimeters.
  Iron absorbers with quartz fibers embedded.

- Long and short fibers alternated to distinguish energy deposits of different particles types.
  Long and short fibers separated in read out.



- 12 x 36 segments in η x Φ.



Fiber read out connected to r-Φ wedges.

Analysis Strategy

Energy flow as a function of rapidity in the forward region – 3.15 < |η| < 4.9

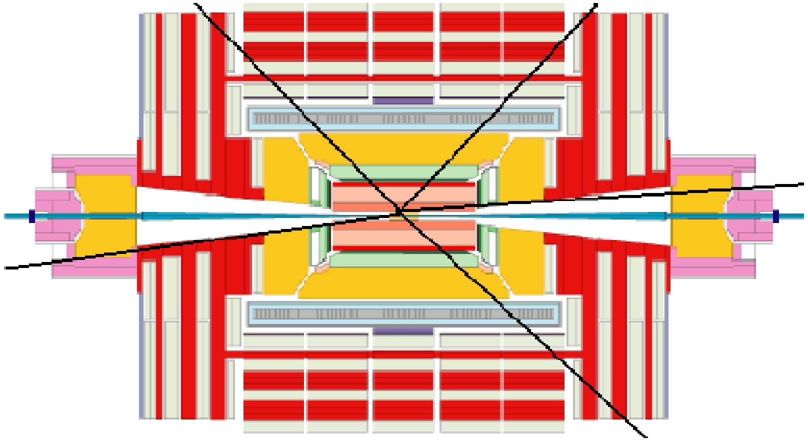
- $$\frac{1}{N}\frac{dE}{d\eta}[GeV]$$

- **Two center of mass energies: √s=0.9 and 7 TeV**

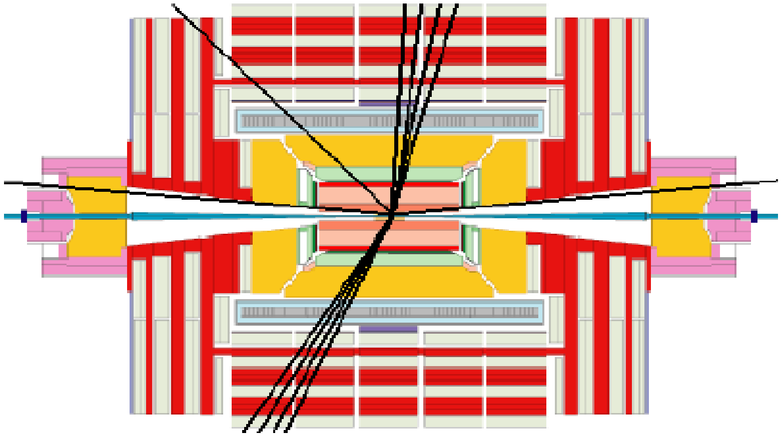
- **Data: 2010, $\mathcal{L}$ (√s=0.9 TeV) = 239 μb^{-1}, $\mathcal{L}$ (√s=7 TeV) = 206 μb^{-1}**

- **Two event types:**

Minimum Bias events
(zero or few partonic interactions)



Events with a hard central dijet system
(one or more high P_T partonic interactions)



- **The measured energy flow has been corrected to hadron level.**

Event Selection

MB event selection

- Events are selected with a Non-Single-Diffractive trigger which requires MB activity in coincidence in both the forward and the backward region.
- + technical cuts such as good vertex selection and rejection of background events.

Dijet event selection

Subsample of the MB events

- Jets are defined with the Anti-k_T algorithm with R=0.5.
- Select events in which the leading and the sub-leading jet fulfills:

	$\sqrt{s}$=0.9 TeV	$\sqrt{s}$=7 TeV
High p_T	p_T > 8 GeV	p_T > 20 GeV
Central	$\lvert\eta\rvert$ < 2.5	
Back-to-back	$\lvert\Delta\varphi_{jet1,jet2} - \pi\rvert < 1$	

In both the analyses:
Energy deposits in the Hadronic Forward within $3.15 < |\eta| < 4.9$ and above noise treshhold (4 GeV) enter the energy flow.

Corrections

- The measurement is corrected for detector effects (migrations, acceptance, noise, resolutions, etc).

- Bin-by-bin corrections for each η bin: Ratio between eflow on hadron level and detect level MC.

$$C_{bin} = \frac{dE_{bin}^{had}}{N^{had}} / \frac{dE_{bin}^{det}}{N^{det}}$$

- Detector level MC (det):
  - Simulated MC events - full reconstruction, analyses chain and event selection as the data

- Hadron level MC, aka Generator level (had):
  - Detector independent
  - Stable particles, excluding neutrinos and muons
  - MB event selection:
    One charged particle in both the forward and the backward region.

  - Jet selection:
    Same as data (last slide)

Anti-kt algorithm (R=0.5)	$\sqrt{s}$=0.9 TeV	$\sqrt{s}$=7 TeV
High p_T	$p_T > 8$ GeV	$p_T > 20$ GeV
Central	$\|\eta\| < 2.5$	
Back-to-back	$\|\Delta\varphi_{jet1,jet2} - \pi\| < 1$	

Systematic and Statistical Uncertainties

- **Energy scale uncertainty: 10%**

- **Model dependent systematic uncertainties**
  Estimated by using different models for the bin-by-bin corrections

  Energy flow in Minimum Bias events: ***3 – 10%***
  Energy flow in dijet events: ***7 – 20%***

- **Uncertainties from**
  - **Position of primary vertex**
  - **Channel-by-channel miscalibration**
  - **HF noise cut**
  - **Hits in the PMT read-out part**
  - **Corrections for geometric uncertainties**
  - **Background (beam gas, pileup)**

  add up to < 5%.

- **Total systematic uncertainty**

  Energy flow in Minimum Bias events: ***11 – 14%***
  Energy flow in dijet events: ***13 – 22%***

- **Statistical uncertainty: < 0.1%**

Overview MC Generators

MC Event Generators 1/2

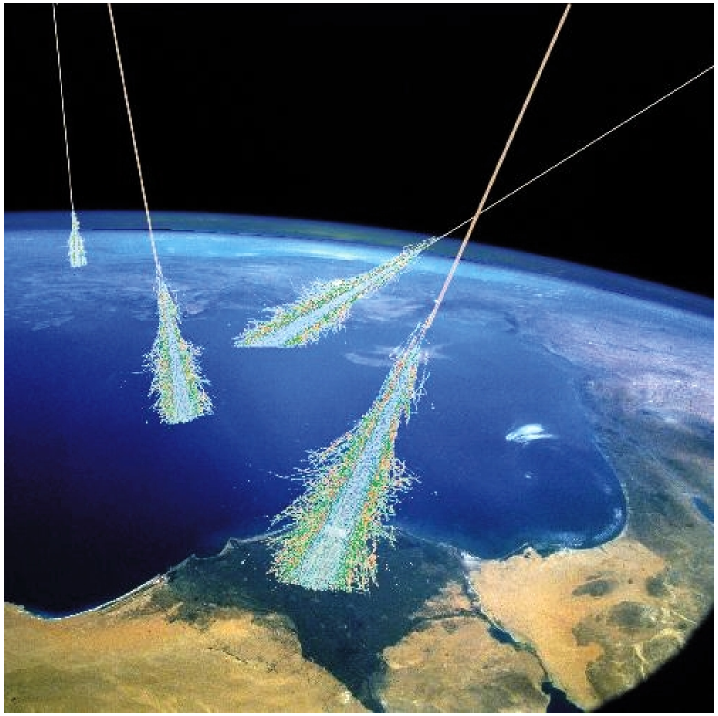
- **PYTHIA 6 (Used for detector corrections)**
  - LO ME + DGLAP parton showers.
  - Fragmentation from the Lund string model.
  - Multiparton interactions (MPI)
  - Extensively tuned to LEP and TEVATRON data. Many tunes exists.

- **PYTHIA 8**
  - The C++ version of Pythia 6.
  - Updated MPI/UE models
  - Hard diffraction included

- **HERWIG++**
  - LO ME + DGLAP parton showers.
  - Cluster fragmentation.
  - Multiparton interactions.

- **CASCADE**
  - Based on the k_t factorization approach.
  - LO ME (off-shell) + CCFM based final state parton showers (no k_t ordering).
  - Unintegrated PDFs.
  - Fragmentation from the Lund string model.
  - No multiparton interactions.

MC Event Generators 2/2



Cosmic Ray MC generators

- QGSJET
- SIBYLL
- EPOS

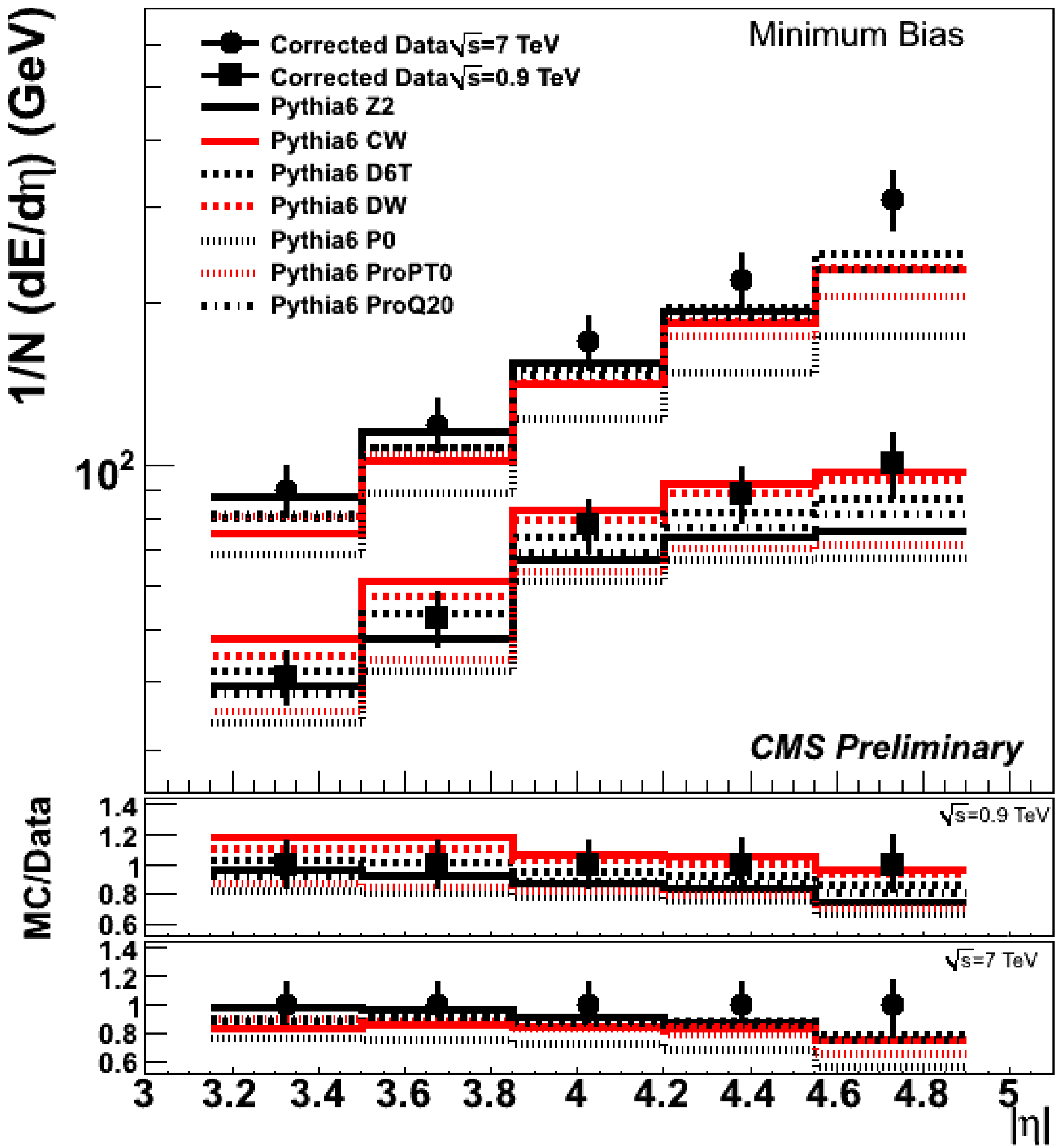
Originally made for cosmic ray – of which 90% are protons – interactions with the atmosphere. (Air shower models.)

Forward particle production important in air shower models – majority of the energy carried by the forward particles.

MC generators QGSJET, SIBYLL and EPOS are based on Regge theory.

Interactions described as multiple Pomeron exchanges, but include also DGLAP parton ladders.

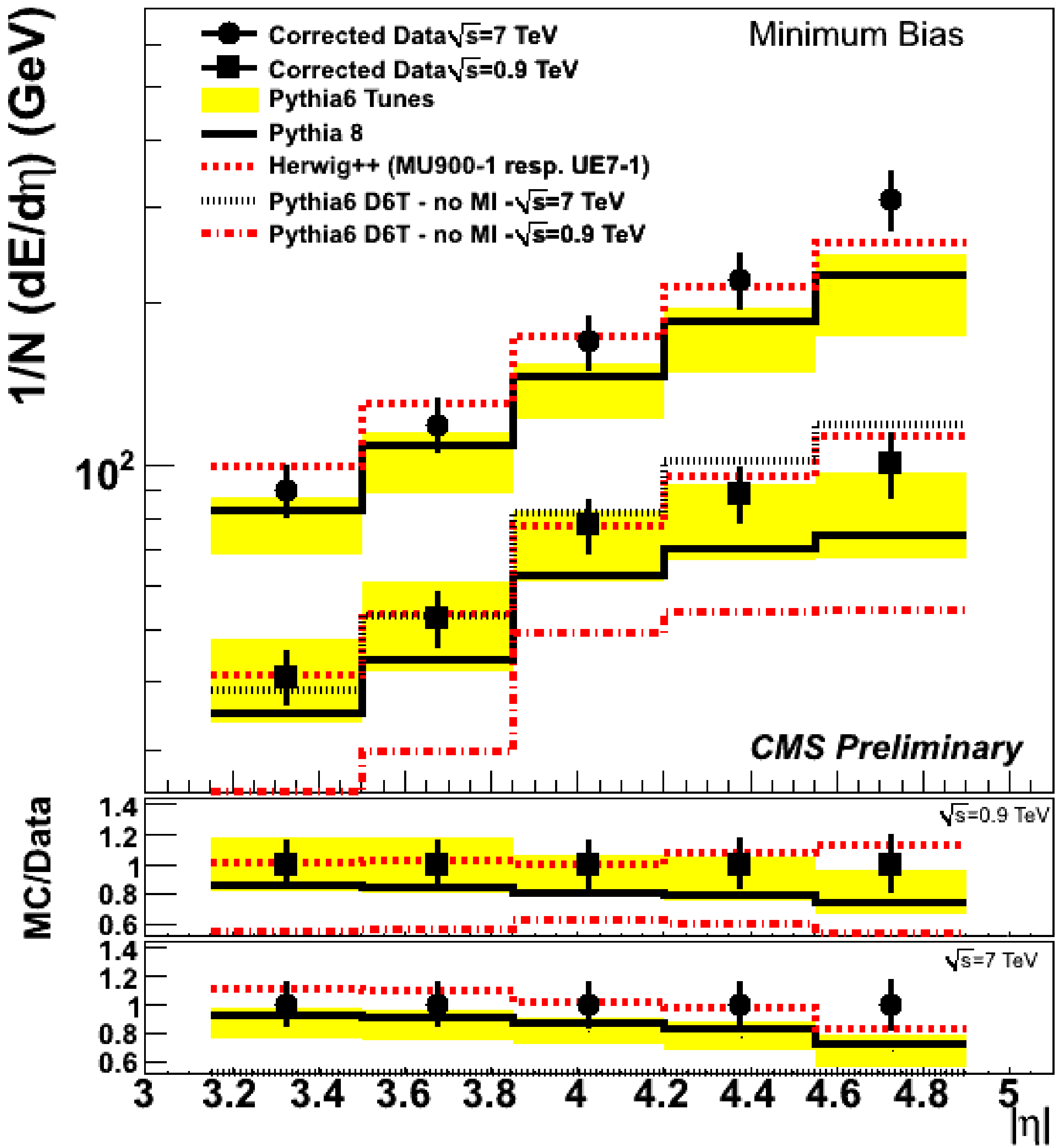
Results



Comparison to Pythia 6 tunes

- Error bars: systematic uncertainties (highly correlated between bins)
- Statistical errors < 0.1%.
- Strong dependence on c.o.m energy.
- Energy flow increase with η.
- No Pythia 6 tune describe the √s = 7 TeV data at high eta.
- Several tunes equally good within errors.
- No systematic difference between tunes done with P_t or Q^2 ordered showers.
- Only tune P0 (Perugia0) can be completely ruled out.

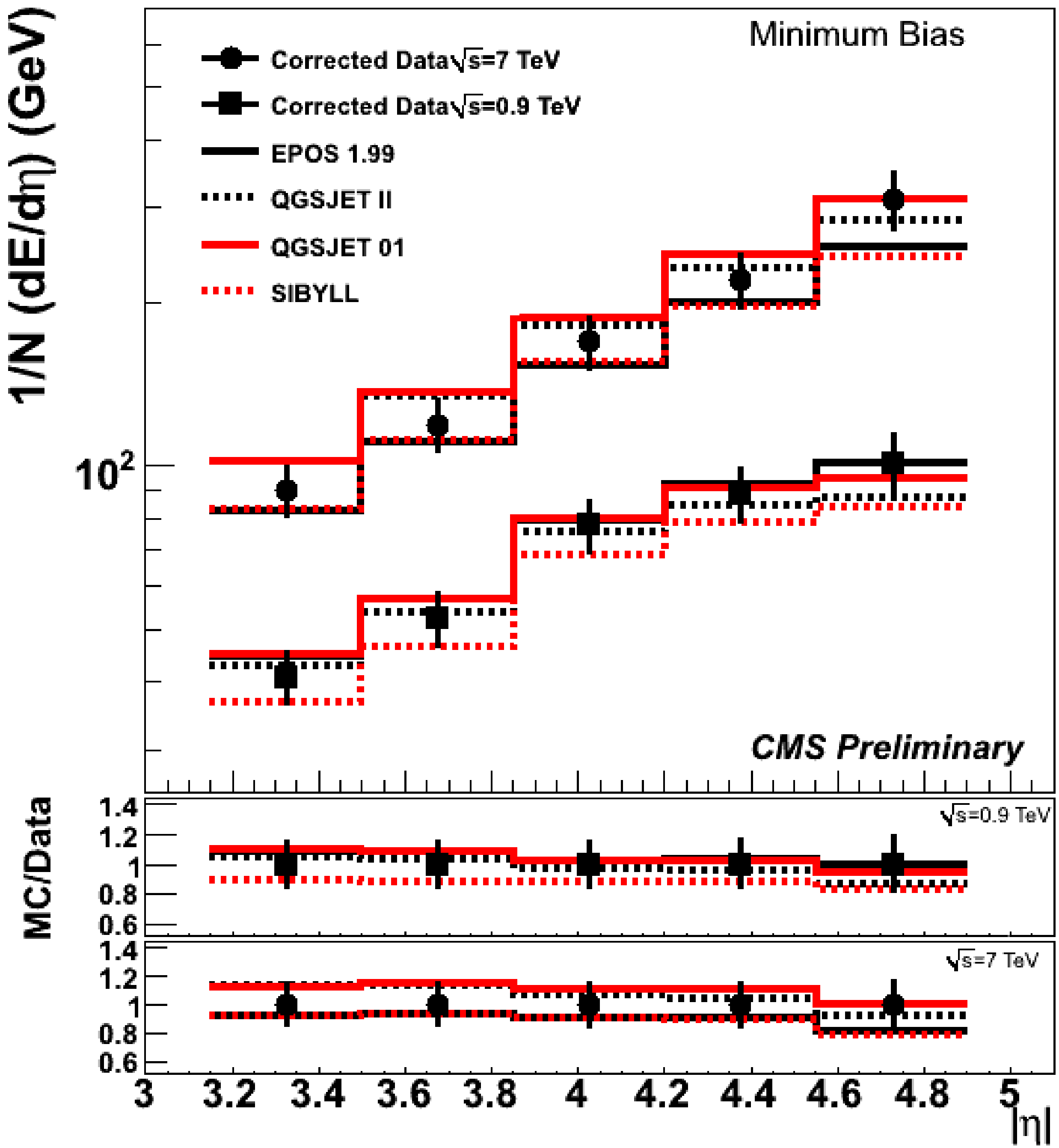
Results – Minimum Bias



Comparison to various MC generators

- Pythia 6 band composed from the different Pythia 6 tunes on the last slide
- Herwig++ describes the data using center-of-mass specific tunes.
- Pythia 8 fails at high eta
- Significant contribution from multiparton interactions.

Results – Minimum Bias



Comparison to Cosmic Ray MC

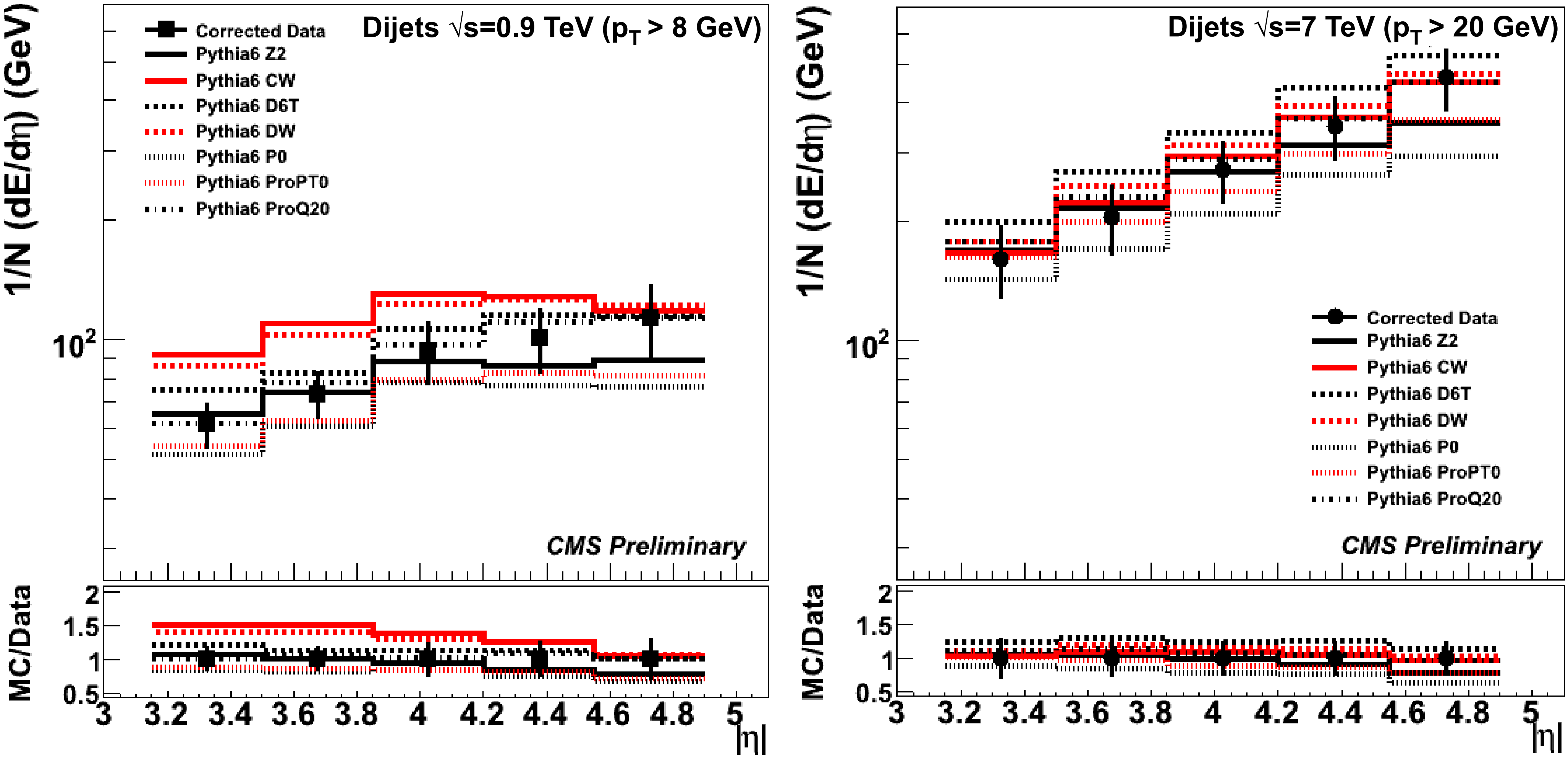
- **Overall very good description by cosmic ray MC generators**

No surprise. Cosmic Ray MC developed for describing the activity in the forward region.

- **Only at highest measured eta a small discrepancy for some of the generators.**

Results – Dijet Events

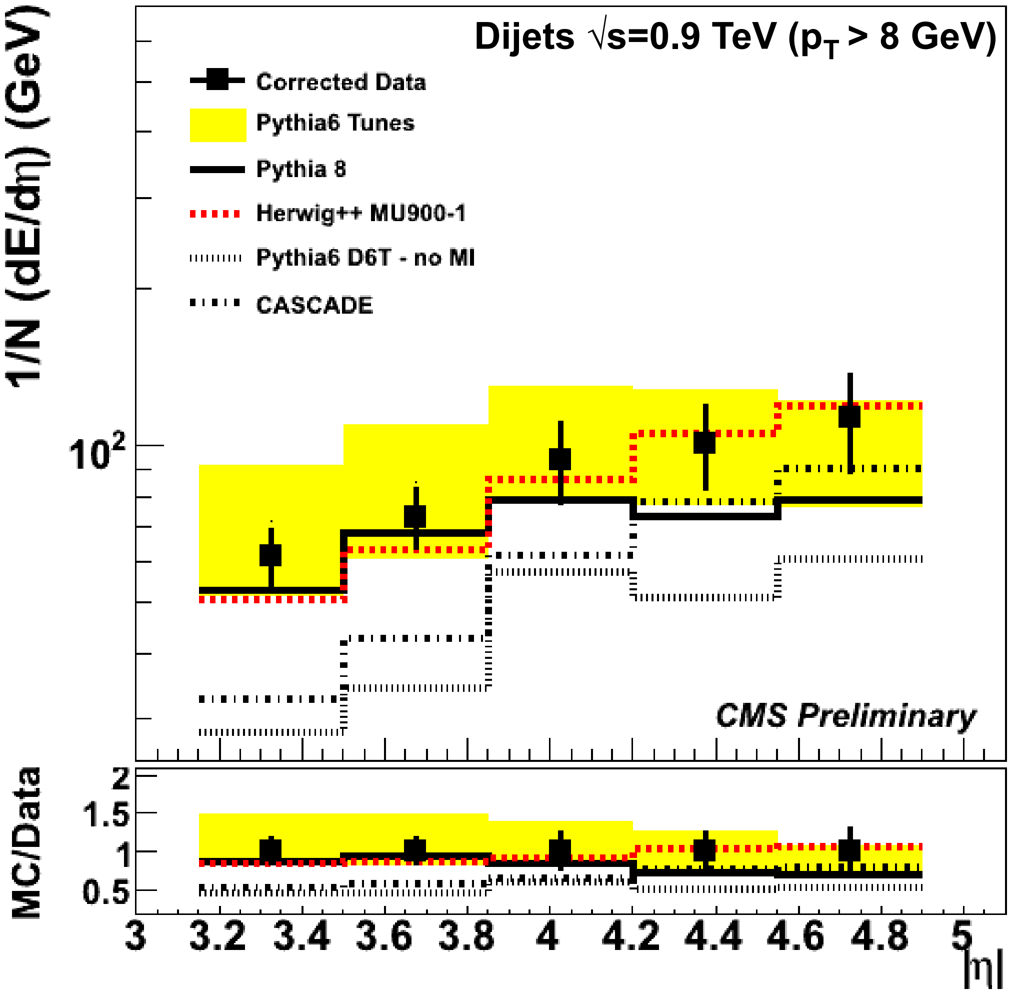
Comparison to Pythia 6 tunes

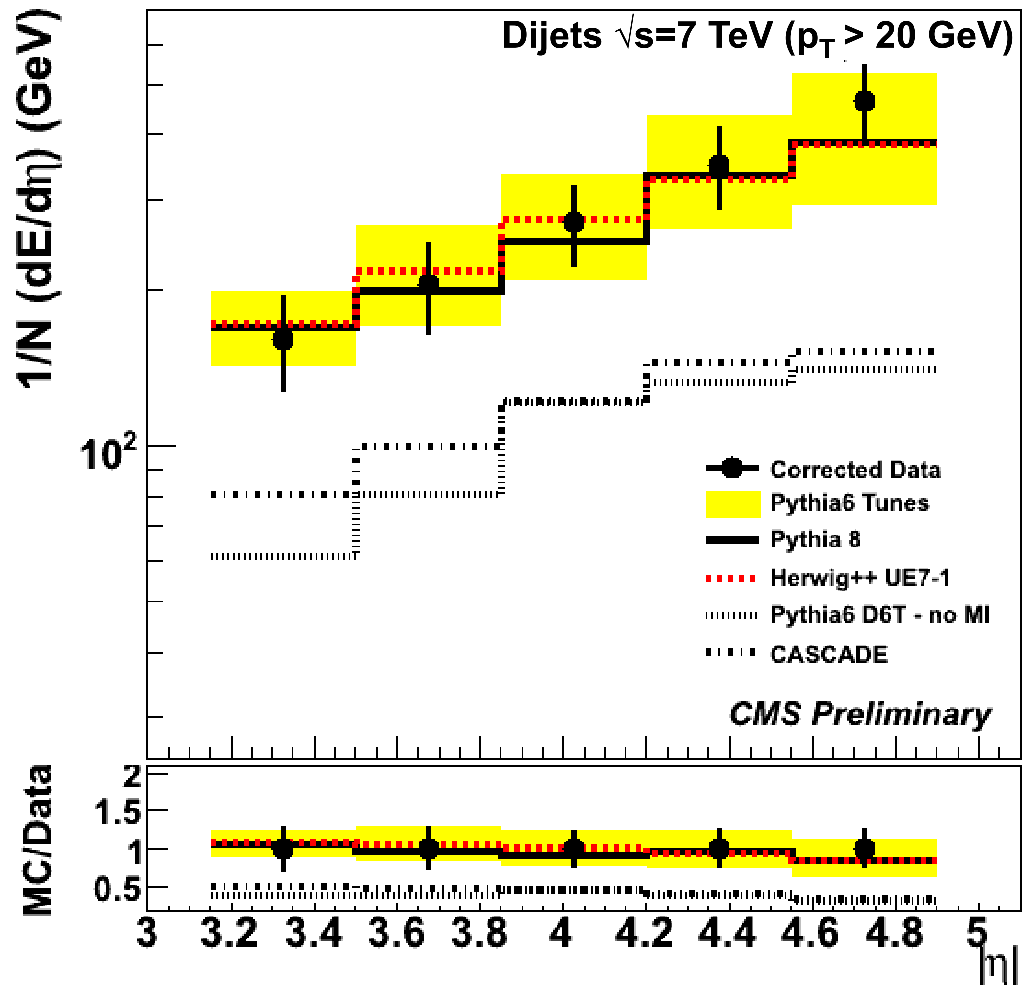


- Significantly higher forward energy flow in dijet events than in MB.
- Somewhat larger spread of the different Pythia 6 tunes compared to in MB events.
- Only one tune describes both the 0.9 and 7 TeV data within the errors.
  ProQ20 (The Professor tune with Q2 ordered showers)

Results – Dijet Events

Comparison to different MC generators

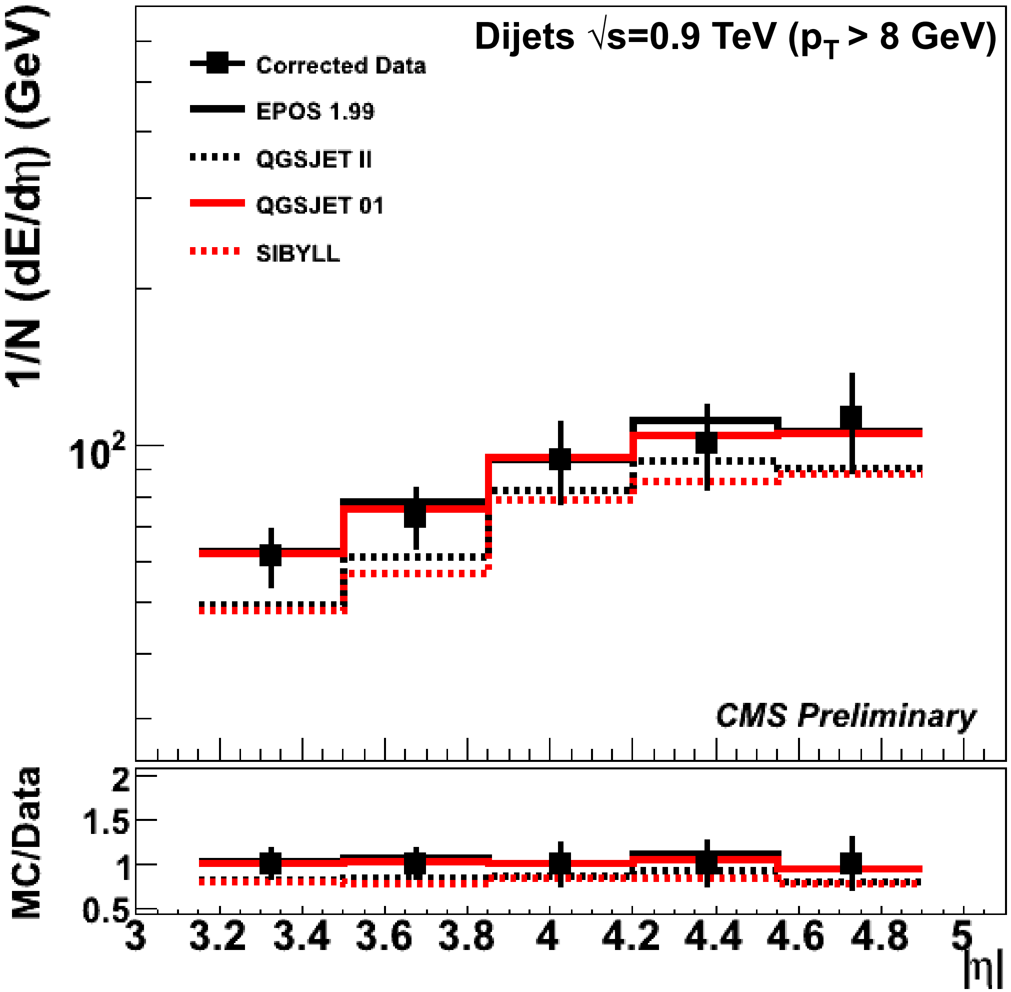


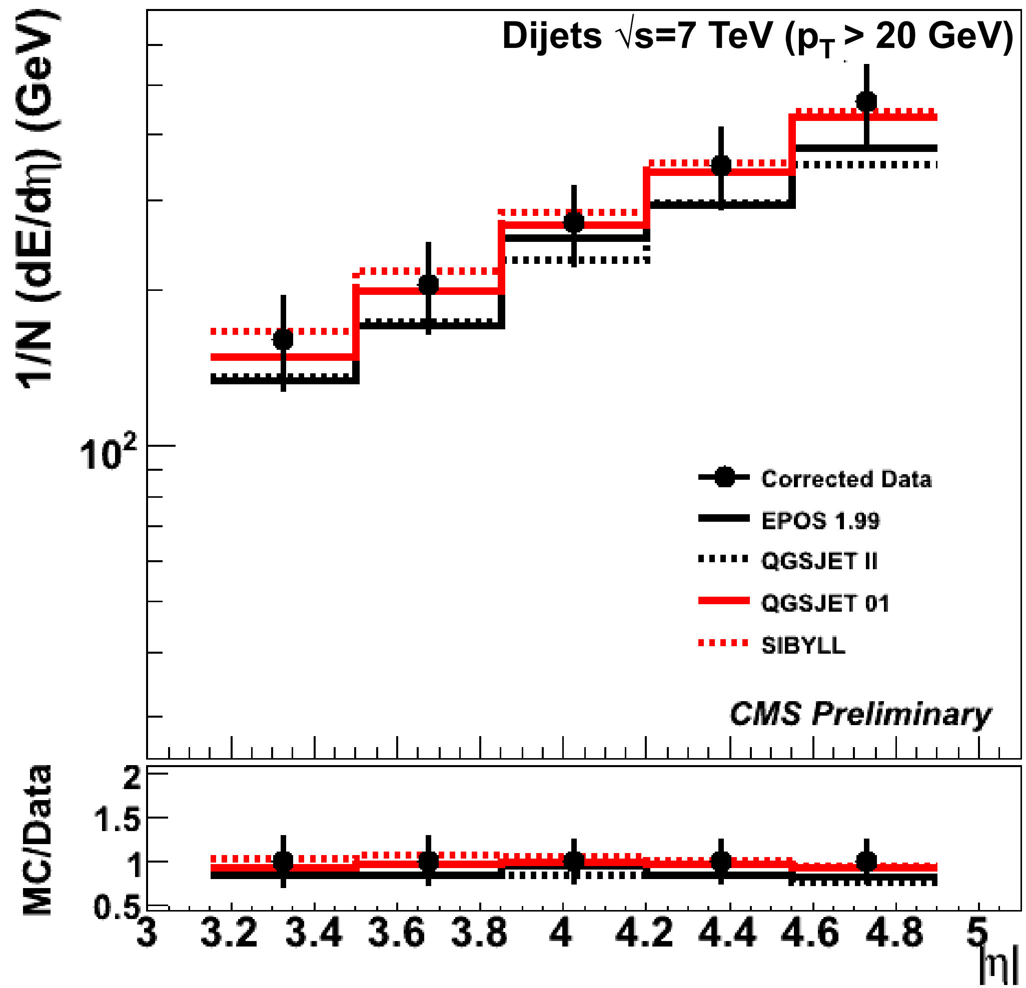


- Pythia 6 band nicely envelopes the data.
- Pythia 8 describes the data at $\sqrt{s}$=7 TeV.
- Herwig++ (2.5) good description when using c.o.m. specific tunes.
- Large contribution from MI.
- Cascade (no MI) produce somewhat more activity than Pythia 6 w/o MI.

Results – Dijet Events

Comparison to different Cosmic Ray MC





- Also here a good description of the data by the cosmic ray MC.
- QGSJET 01 does an excellent job at both center of mass energies.
- Small difference between the Cosmic Ray generators.

Summary

- The energy flow has been measured in the forward region - $3.15 < |\eta| < 4.9$, at $\sqrt{s}=0.9$ and $\sqrt{s}=7$ TeV, for MB events and events with a hard central dijet system.

- Kinematic region unexplored (in terms of UE/QCD) in previous collider experiments.

- Similarities to convectional UE measurements:
  - Energy flow in the forward region depends strongly on center-of-mass energy, and the QCD scale in the event.
  - Significant contribution from multiparton interactions.
  - Sensitivity to UE tunes and models.

- Data described by MC generators, but no single MC generator or tune describes the energy flow in both MB and dijet events at both center of mass energies.

- Cosmic Ray MC generators do a very good job in describing *all* the presented data.

- High sensitivity to models and tunes $\longrightarrow$ Use the data for future MC tuning and improvement of UE models.